Report No. 62

Ground-Water Movement at the Balloon Track Site, Eureka, California

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prepared for:

Lawyers for Clean Water
San Francisco, California

Contents

1 Introduction **1**

2 Professional background **1**

3 Geology **2**

4 Hydrogeology **7**

4.1. Ground-water recharge 8

4.2. A-Zone ground water in the wet season 8

4.3. A-Zone ground water in the dry season 10

4.4. Alternative interpretations and data gaps 12

4.5. B-Zone ground water 13

5 Summary of conclusions **14**

A Curriculum vitae, Benjamin Ross, Ph.D. **16**

B Survey results **19**

C Influence of tides on ground water **24**

D Documents used to prepare report **27**

1. Introduction

Lawyers for Clean Water, on behalf of the Humboldt Baykeeper and the Ecological Rights Foundation, asked me to evaluate ground-water movement at the Balloon Track site formerly operated by Union Pacific Railroad in Eureka, California.

My opinions are based on my professional knowledge and experience, on review of documents prepared by Union Pacific and its consultants, on data and observations collected at the site by other experts working for Plaintiffs in this case, on an inspection of the site on January 10, 2008, on data from government agencies, on historical aerial photographs of the site, and on internet and library research.

This report is organized as follows. Section 2 summarizes my professional background. The following section describes the geology of the Balloon Track site. The final section discusses ground-water movement at the site. There are four appendices; the first is my Curriculum Vitae, the second is the results of a survey during the inspection, the third discusses the tidal movement of ground water in an aquifer that discharges into an estuary, and the fourth is a reference list.

All the figures in this report may be used as exhibits at trial. I am compensated for my work on this case at a rate of $270.00 per hour, plus travel and other expenses.

2. Professional background

I am a Certified Ground Water Professional. I served for six years on the Committee on Remediation of Buried and Tank Wastes established by the National Academy of Sciences. I have also served on two subcommittees of the U. S. Environmental Protection Agency Science Advisory Board. My professional qualifications are described in more detail in my Curriculum Vitae, which is attached to this report as Appendix A. The Curriculum Vitae includes a list of publications.

I have presented trial testimony on the direction and speed of ground water movement in two Federal court cases, *Woodman v. U.S.* in the Eastern District of Florida and *Interfaith Community Organization v. Honeywell* in the District of New Jersey. I testified about the underground movement of non-aqueous liquid pollutants for the United States Dept. of Justice in *U.S. v. Borden* in the Middle District of Louisiana.

I gave deposition testimony on tidally influenced ground water flow in a case in the Contra Costa County Superior Court, *Baykeeper v. Dow.* This case concerned a factory located on a slough in the San Francisco Bay Delta. My calculations of the tidal influence on ground-water movement for this case were subsequently published [26] in the peer-reviewed journal *Water Resources Research*, published by the American Geophysical Union.

During the last four years, I have presented deposition testimony in one case, the *Redlands Tort Litigation* in the Superior Court for San Bernardino County, Western Division.

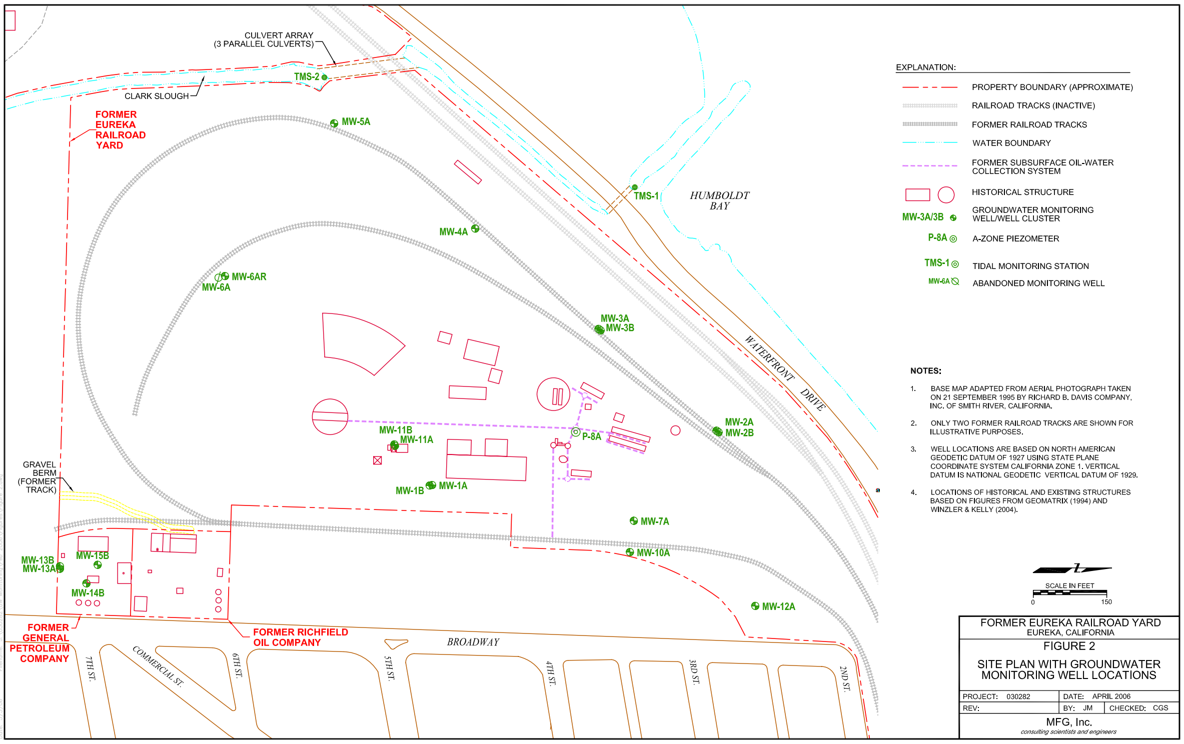

Figure 1: Site map showing locations of borings and other features.

3. Geology

The Balloon Track site occupies a roughly trapezoidal area on the southern shore of Humboldt Bay. (The site is defined in this report to include the former General Petroleum and Richfield Oil properties in addtion to the former Union Pacific railroad yard; ground and surface water flows on the former properties interact with flows on the railroad yard, which they adjoin.) Figure 1 is a site map prepared by consultants to the property owners, showing the location of monitoring wells and other features. The site is bounded on its northwest by Waterfront Drive; docks and the Eureka Marina are located across the road. On the east, it is bounded by Broadway and by commercial properties that front on Broadway. To the south it is bounded by other commercial properties; to the west it is bounded by Clark Slough. The site is low-lying; surface elevations range from approximately 4 ft to 9 ft. Figure 2 is a contour map that shows surface elevations and drainage as of 1995.

The portion of the subsurface that is of interest in this case is divided into three layers. The uppermost layer is artificial fill. Beneath the fill is an estuarine clay referred to as the Bay Mud. Beneath the Bay Mud are natural sandy sediments.

Artificial fill is exposed at the surface in all portions of the site. Typical fill thickness is 6 ft. Descriptions of the fill are available from numerous borings and trenches. [24, 36, 12, 30, 19, 32, 33, 9, 25, 20] The fill is predominantly composed of poorly sorted sands. However,

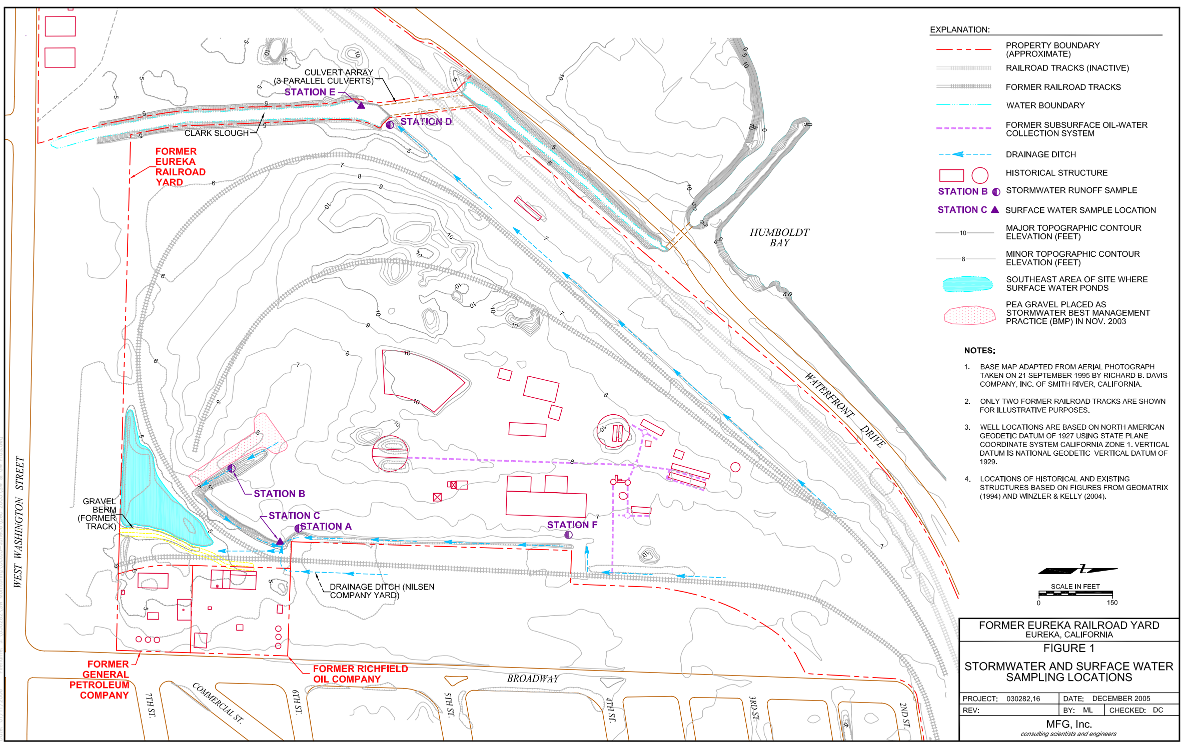

Figure 2: Contour map showing elevations and drainage as of 1995.

Figure 3: Aerial photograph showing the site circa 1950. View from the south.

reworked Bay Mud was encountered in the fill zone in at least two trenches, T-12 and T-23, and in Boring G-65. [12, 31]

The site was filled in two stages. The northeastern portion of the site, where the railroad maintenance operations were conducted, has been filled for roughly 100 years. In the same era, the balloon track was constructed on an artificial berm built through the wetlands. [10] The remainder of the site was filled in the decades after World War II. Figure 3 shows the site at the beginning of the second phase of filling.

The Bay Mud is a clay or clayey silt. Its thickness ranges from less than 1 ft in Borings G-68 and G-73 to as much as 7 ft. In Boring G-72 no native clay layer was encountered. [9] The elevation of the upper contact of the Bay Mud is shown on Fig. 4. In the western half of the site, the elevation ranges from 2 to 4 ft above sea level[1]; in the eastern half it ranges from −1 to 2 ft. This elevation trend can be seen in the aerial photograph of Fig. 3, where the ground surface in the unfilled portion of the site is covered with water to the east and exposed to the west.

In several areas of the site, numerous soil borings allow one to examine the configuration of the top of Bay Mud on a fine scale. [33, 32, 9, 30] The measured top-of-clay elevations near the former Union Pacific underground storage tanks are shown on Fig. 5. Here and elsewhere on the site, the surface is irregular with a small-scale variability of approximately

[1]The elevation of the top of the Bay Mud in Well MW-4A is uncertain. The ground surface elevation of 8.7 ft shown on the well log [12] is incorrect; the top-of-casing elevation, as measured both by MFG [21] and during our site inspection (see Appendix B) is 8.9 ft. The top of casing is visibly more than 0.2 ft above the ground surface. Also, if the elevations shown on the well log were correct, the measured water levels of 2.73 ft in August 2004 and 2.92 ft in August 2006 [21] would be below the bottom of the well screen.

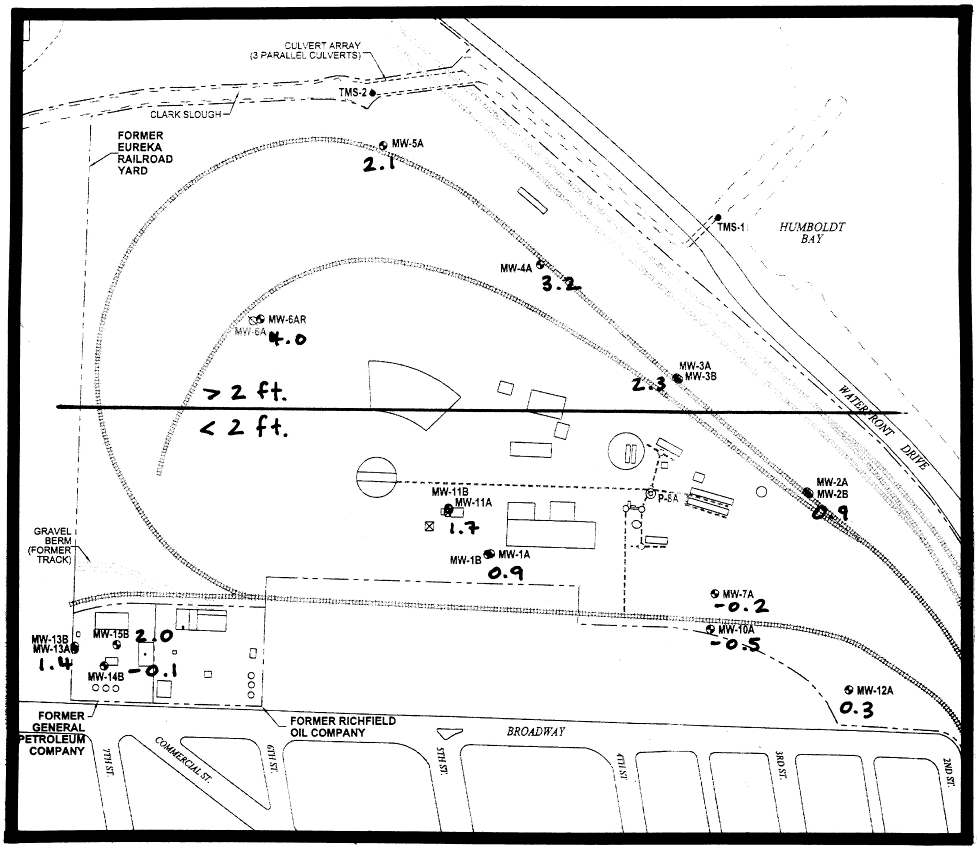

Figure 4: Elevation of upper contact of Bay Mud. Elevation values shown only at monitoring well locations for reasons of scale. North is to the right.

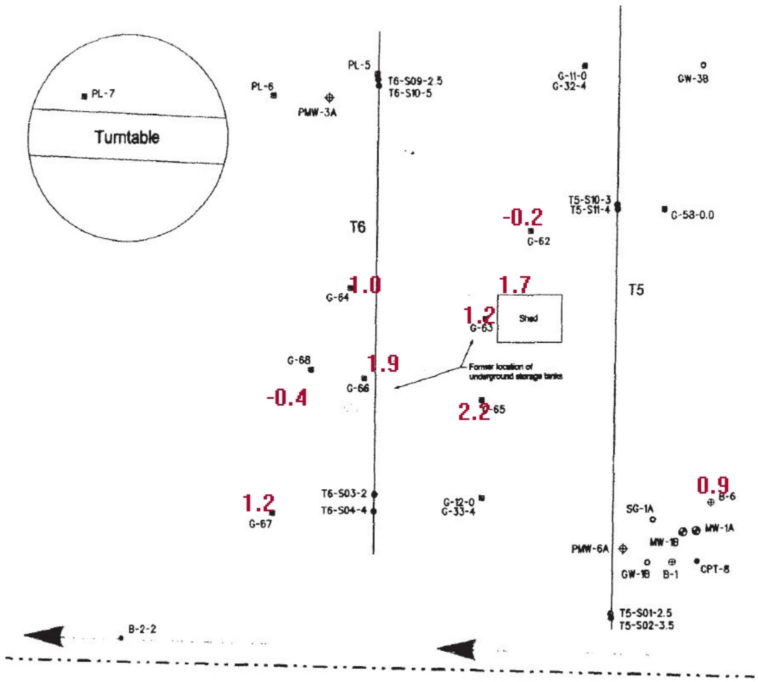

Figure 5: Measured elevations of upper contact of Bay Mud in the area of the former Union Pacific underground storage tanks. Location of monitoring well MW-11A approximate. North is to the right.

±1 ft.

There are gaps in the Bay Mud through which ground water flows. Such gaps exist in the area of the former rail maintenance operations, and probably elsewhere. Evidence for such gaps includes:

- The Bay Mud was absent in Boring G-72, located on the former General Petroleum property. [9]
- The upper contact of the Bay Mud is irregular on a small scale in the three areas where there is a high density of data.
- Two of seven borings in the former maintenance area had Bay Mud thicknesses of 1 ft or less. [32]
- Construction of building foundations may have disturbed the Bay Mud.
- The turntable track, located several feet below the ground surface, rests on a circle of wooden beams. In the nearest boring (G-64), the ground surface elevation is 7.97 ft and the top of the Bay Mud is 7 ft below the ground surface. [32] The builders of the turntable seem to have replaced the relatively thin layer of plastic Bay Mud with ballast to provide a firm foundation and to provide drainage. On the date of my inspection, Jan. 10, 2008, the bottom of the turntable was only partially covered with standing water, and the water level was below the top of the wooden beams. This places it a substantial distance below the water table as it manifested itself in the L-shaped ditch during my visit and as

measured during previous winter sampling events, but above the potentiometric level in the sands beneath the Bay Mud (see below). This water level shows that standing water in the turntable must be in hydraulic communication with ground water below the mud layer.

- Diesel-range petroleum hydrocarbons have been detected in wells screened below the Bay Mud. [12]

Beneath the Bay Mud is a natural layer of poorly sorted fine to medium sand. The thickness of this layer is at least 50 ft.

4. Hydrogeology

Site hydrogeology is discussed in numerous reports by Geomatrix and other consultants to Union Pacific. Consultants to Wal-Mart, which considered building a store on the site, gave a summary of the conclusions reached by GeoMatrix [18]:

> Groundwater occurs in 2 water-bearing zones, termed the A-Zone and the B-Zone. These zones correspond to the fill unit and the [natural] sandy unit, respectively. The 2 zones are separated by the estuarine clay, which acts as an aquitard.
>
> The A-Zone, which occurs under unconfined conditions, has a saturated thickness that varies seasonally from 0 to 5 feet. The source of A-Zone groundwater is on-site infiltration of rainwater. The water table is high in the central area of the site, and the horizontal hydraulic gradient is to the south, west, and east. Shallow groundwater does not flow directly toward Humboldt Bay, possibly because of a subsurface barrier, such as less permeable fill, near Waterfront Drive. The lack of connection between the A-Zone groundwater and Humboldt Bay was confirmed by a tidal influence study (Geomatrix, 1994) which indicated no tidal influence in the A-Zone, in wells along the northern side of the site. The mounding of the water table is a function of infiltration, elevation of the top of the estuarine clay unit, the variable nature of the fill material, and evapotransporation.
>
> The B-Zone, which occurs under confined conditions, has a thickness of at least 50 feet. B-Zone water level elevation data indicates that in this zone, flow is generally toward Humboldt Bay. The direction of the horizontal hydraulic gradient direction varies depending on tidal stage; higher groundwater elevation directions are measured in the wells close to the bay shortly after high tide. The source of B-Zone groundwater likely is groundwater flowing onto the site from industrial areas in Eureka, to the south and east.

The description of the hydrostratigraphy here is accurate and I will use the same nomenclature in this report. However, there is no basis for the assertion that shallow ground water does not flow into Humboldt Bay. Measured water levels show flow toward the bay and, as discussed in Appendix C, the tidal influence study gives no indication that a flow barrier exists.

4.1. Ground-water recharge

Precipitation in Eureka is very seasonal. The rainy season, which lasts from October through April, accounts for about 90 percent of the annual precipitation. [23]

In April 1996, Geomatrix studied storm water runoff from a rainstorm during a period of wet weather. [29] They found that

> Most of the rainfall at the site is likely to infiltrate the subsurface through the coarse-grained surficial soils or to temporarily pond and later evaporate.

I inspected the site on Jan. 10, 2008, after a heavy rainstorm (precipitation of 4.75 inches was measured in the preceding seven days), and my observations supported the conclusion that much of the rain water that falls on the site infiltrates into the A Zone. There were numerous areas of ponded water and saturated or very wet soils were present across much of the site.

A site feature that illustrates the preponderant tendency of rain water to infiltrate is the north-south swale that runs along the eastern boundary of the site (the "east ditch"). The east ditch terminates in a relatively deep L-shaped depression.[2] During and after rains, rain water enters the depression directly, through the east ditch, and by overland flow. Evaporation is a small fraction of precipitation in the winter climate of Eureka. Thus a large proportion of the precipitation in the drainage of the east ditch must recharge the A Zone, either directly or through the L-shaped depression.

4.2. A-Zone ground water in the wet season

The A Zone is a water-table aquifer. The configuration of the water table varies in response to the highly seasonal pattern of precipitation and in response to individual storm events.

In the wet winter season, much of the ground-water flow pattern can be explained by the classic principle [2] that the water table is a subdued version of the topography. The water-table configuration measured at the time of the most recent winter monitoring event [27] is shown in Fig. 6. The highest water levels are in the center of the site around Well MW-6A. Water flows radially outward and discharges around the perimeter of the site. Consultants to the site owners reached a similar conclusion:

> On February 19, 2007, it appeared that a shallow groundwater mound had developed in the A-Zone aquifer, in the central portion of the site. This resulted in a radial groundwater flow pattern.

Areas of winter ground-water discharge include:

- The wetland in the southeast portion of the site. The location of this wetland is shown in the maps accompanying the 1996 Geomatrix storm runoff study. [29] Evidence for ground-water discharge in this wetland includes its location in a topographic low, its vegetation (predominantly cattails), and the well-defined outlet channel.

[2] At the time of my visit, surface water was flowing out of the depression at two locations.

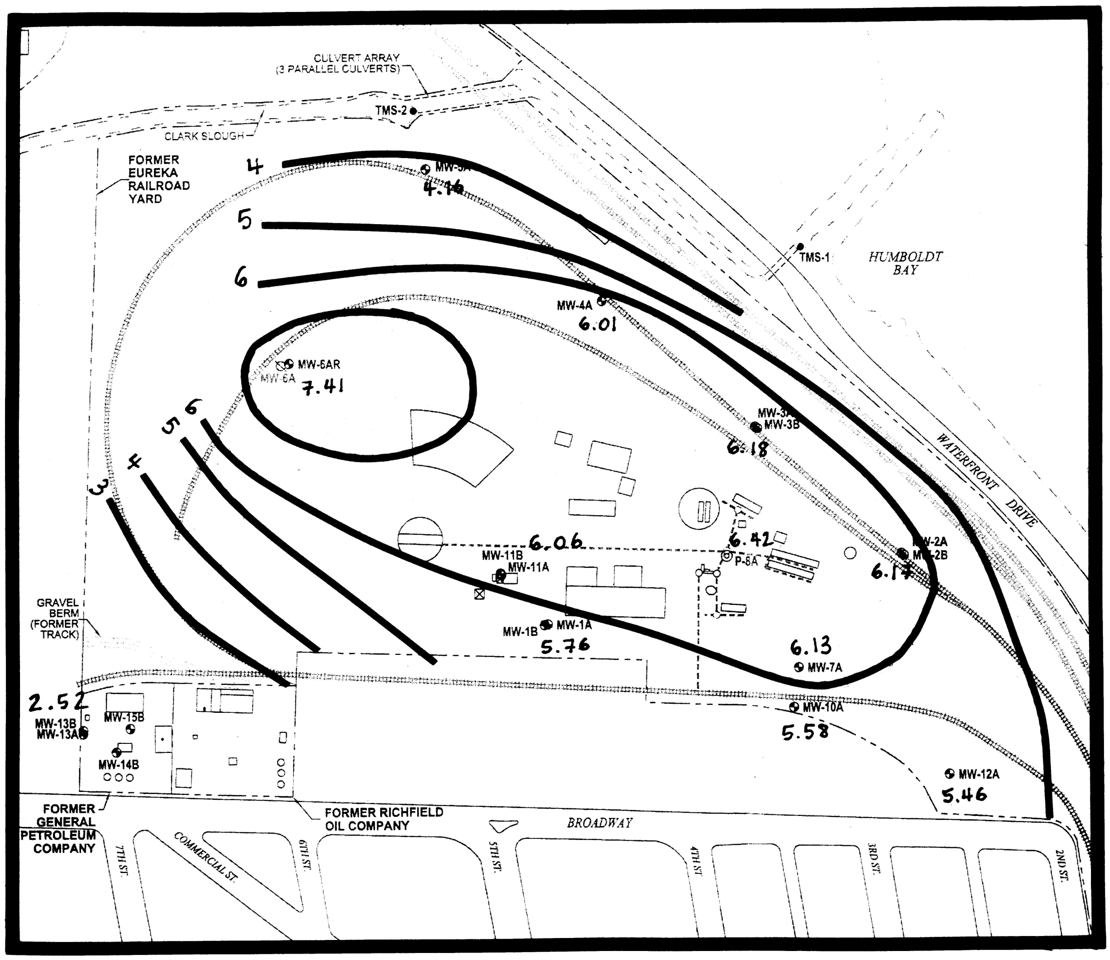

Figure 6: Water table configuration on February 19, 2007. North is to the right.

- The watercourse that drains the southeast wetland and terminates in a culvert under the southern boundary fence. Its elevation is below the wetland and it is located closer to the ground-water divide around MW-6A than the wetland is. Cattails grow on the entire north bank of this stream but only on the lower portion of the south bank.
- Clark Slough.
- The ditch that runs parallel to the former balloon track along the northwest side of the property and flows into Clark Slough through a pipe (the "western ditch"). I observed ground water discharging into this ditch.
- Humboldt Bay.

Ground water may also discharge into the swale that runs along the southern property line to the west of the culvert.

The pattern of ground-water flow during the wet season varies as the water table fluctuates in response to storms and periods of dry weather. At times such as my inspection (4.75 in. of rain fell in the preceding 7 days [35]) and an inspection by consultants to a potential developer of the site, [19] the water table is within inches of the surface over much of the site. After rains end, the water table drops rapidly. Two water-level measurement events six days apart, on April 25 and May 1, 1996, showed a water level decline in just six days of six inches to more than a foot in A-Zone wells throughout the site. [30]

The L-shaped depression, whose bottom has a surveyed elevation of 2.24 ft (see Appendix B) which is below the winter water table elevation at this location, must contain water during much or all of the winter. As noted above, it is a recharge feature during and immediately after rains. Once a sufficient time has passed after a precipitation event, the water level in the depression is a manifestation of the water table. Ground water then flows through the depression toward the discharge in the wetlands to the southeast.

4.3. A-Zone ground water in the dry season

In the dry summer season, the water table becomes less reflective of the topography and stratigraphic controls on ground-water flow become more important. In the area around MW-6A where the Bay Mud reaches its highest elevation, the water table drains. The rise in the Bay Mud becomes a flow barrier and separates the A Zone into distinct regions. As the dry season proceeds, the water table in a region flattens as the lack of recharge causes the rate of flow to decline and the flattened water table approaches its discharge elevation (which in turn may reflect a complex interplay of surface drainages, evapotranspiration, the top of the Bay Mud, and the tides). Figure 7 shows the water-table configuration in August, 2006. The principal regions of dry-season flow are:

- The northwestern and far northern portions of the site discharge directly into Humboldt Bay.
- The southeastern and east-central portions of the site discharge into the southeastern wetland and southeastern ditch. There may also be discharge by evaporation from the L-shaped ditch.

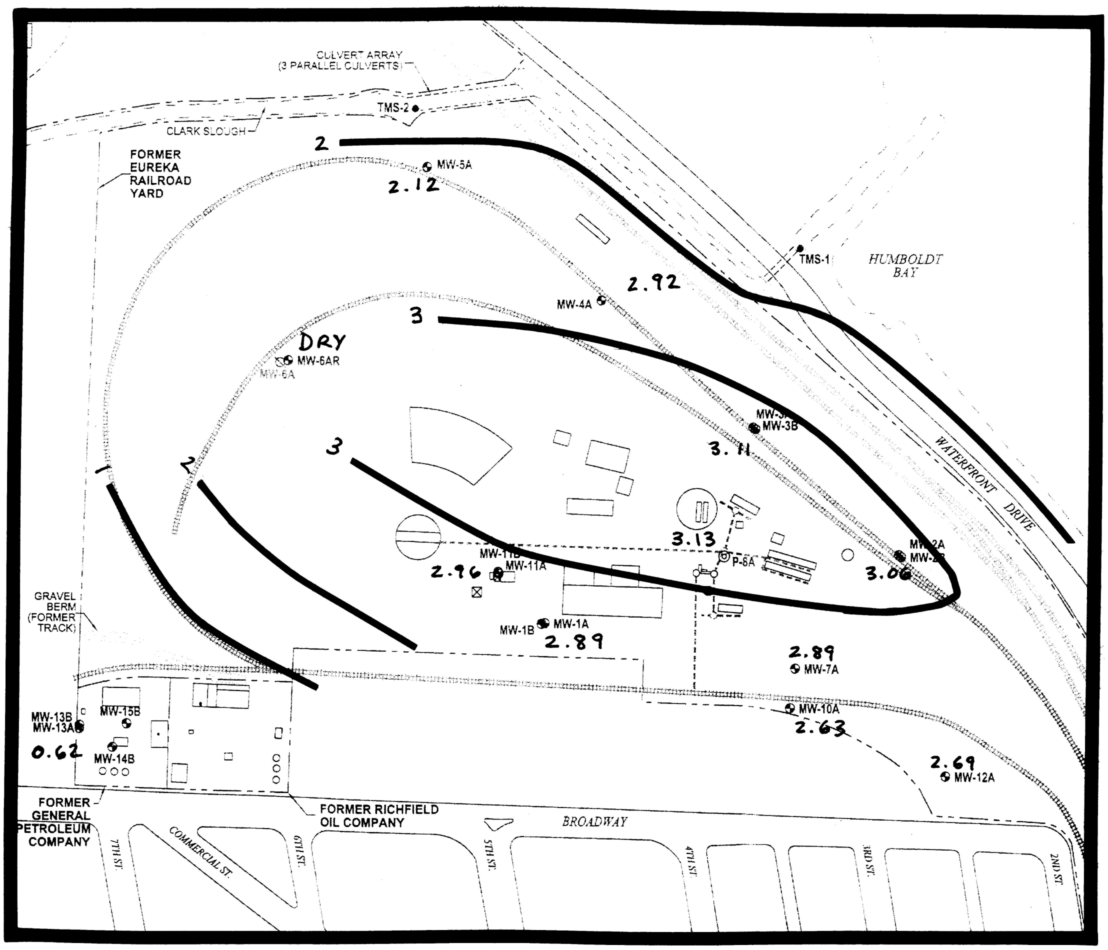

Figure 7: Water table configuration on August 22, 2006. North is to the right.

- The southwestern portion of the site discharges into Clark Slough or into the farthest downstream portion of the western ditch.

4.4. Alternative interpretations and data gaps

Along the northwestern boundary, Union Pacific's contractors contend [12, 14, 15, 20, 21] that there is a flow barrier that prevents discharge of A-Zone ground water directly into Humboldt Bay. The only evidence cited in support of this contention is the absence of tidal fluctuations in the A Zone.[3] As shown in Appendix C, the absence of tidal fluctuations is not evidence for the presence of a flow barrier. And water-level measurements show that ground water does flow in the direction toward Humboldt Bay:

- In the seven rounds of ground-water level measurement between February 2004 and February 2007, water levels were always higher in P-8A, located near the oil storage tank, than in MW-2A and MW-3A which are between P-8A and the bay. [21, 27]
- The rapid decline in water levels at MW-10A and MW-7A from April 25 to May 1, 1996 [30] suggests that these wells are located near a ground-water divide.
- On November 13, 1995, when winter rains had apparently not yet begun, Well MW-5A was dry, as was MW-6A. Wells MW-3A and MW-4A had water. [28] This is inconsistent with Geomatrix' interpretation that water flows from MW-3A and MW-4A toward MW-5A.

In the southeastern region, water-table maps prepared by Union Pacific contractors show flow towards an off-site discharge without discharge into the wetlands or the ditch. This is very unlikely:

- Vegetation grows asymetrically on the banks of the ditch (see Fig. 8). On the north side, facing the site, there is wetland vegetation all the way to the top of the bank. On the south side the wetland vegetation grows only on the lower part of the bank. This indicates that the north bank is saturated year-round, and water discharges into the ditch from the site.
- Water levels in Well MW-13A, located near the wetland, ranged from 0.4 ft to 1.1 ft in recent August monitoring events. [21] The ground surface elevation at MW-13A, which is above the wetland, is 4.38 ft, [25] and the elevation of the drainage from the wetland, at a downstream point, is 3.15 ft (Appendix B); thus the ground surface elevation in the wetland is less than 4 ft. The depth to water in the wetland during the dry season is at most two or three feet, which is less than the root depth of cattails, [1] which are the major vegetation in the wetland. Discharge by evapotranspiration therefore occurs in the dry season.
- The saturated thickness of the A Zone to the southeast of the wetland is negligible in

[3] The difference between the water level in wells in the northwestern part of the site and the mean water level in the bay is not evidence for a flow barrier. If water from the area of Wells MW-3A, MW-4A, and MW-5A does not discharge directly to the bay, it discharges to Clark Slough. The mean water level in Clark Slough is lower than the mean water level in the bay because there is a tide gate at the entrance to the slough. The explanation of the water level difference lies, more likely, in the interaction between tides and the elevation of the top of the Bay Mud.

Figure 8: South ditch, showing the greater growth of cattails on the north bank. Photo looking east, taken Jan. 10, 2008.

the summer. Well MW-13A was dry when drilled in September 2000, and water was encountered in the companion deeper well MW-13B only in the B Zone. In subsequent summer water-level measurements, the water level in MW-13A was below the top of the Bay Mud in that well. In Wells MW-14B and MW-15B, located near MW-13A but with a slightly lower elevation of the top of the Bay Mud, drillers reported encountering water only about three inches above the top of the Bay Mud.

A significant data gap exists between the discharge area at the southeastern wetland and ditch and the area of soil contamination around the turntable. In the absence of monitoring wells, the precise configuration of the water table in this area cannot be determined and ground-water quality is not known. Another area where data are absent downgradient from a source area is the northeastern part of the site, where there are no monitoring points available to determine the quality of water discharging into Humboldt Bay.

4.5. B-Zone ground water

A preponderance of evidence supports the conclusion reached by Geomatrix that B-Zone ground water moves in a north to northwesterly direction and discharges into Humboldt Bay. In the absence of pumping to the east or south of the site, the direction of flow would be expected to be toward Humboldt Bay, the lowest water elevation in the region.

However, there are not enough data to demonstrate this conclusion with certainty.

The combination of few measuring points, a small hydraulic gradient, and effects of tidal and weather-related water-level fluctuations in the bay makes it difficult to determine the flow direction from existing water-level measurements. As discussed in Appendix C, fluctuations in the water level of the bay that have a longer period than the 12-hour tidal cycle will propagate farther inland than the tidal fluctuations. Because weather- related fluctuations do not have the same regularity as the tides, it is very difficult to adjust for their effect on water level measurements.

Flow toward the east or south cannot be definitively ruled out without either a much more detailed study of tidal effects on ground-water levels or a determination of whether ground water is pumped from the area near the site. It is difficult to exclude the possibility of pumpage because water might be pumped for dewatering purposes or for water supply.

As discussed above, there are gaps in the Bay Mud layer through which the A and B Zones are connected. Because potentiometric levels are higher in the A Zone, flow through such gaps is downward into the B Zone.

5. Summary of conclusions

My conclusions about ground-water flow at the Balloon Track site include the following:

- The uppermost aquifer, the A Zone, is hydraulically connected to the aquifer beneath, the B Zone, through gaps in the intervening Bay Mud aquitard. Water flows downward through those gaps.
- Much of the precipitation at the site recharges the A Zone.
- Flow in the A Zone varies seasonally and in response to individual storms or periods of rainy weather.
- In the wet winter season, A-Zone water flows radially outward from the center of the site. During the winter, ground water discharges into the southeast wetland, the southeastern ditch, Clark Slough, the western ditch, and Humboldt Bay.
- In the dry summer season, the water table falls and the rate of flow in the A Zone declines. During the summer, ground water discharges into Humboldt Bay, the southeastern wetland, the southeastern ditch, and Clark Slough.
- There is no evidence to support the hypothesis that a flow barrier prevents discharge of A-Zone ground water from the site into Humboldt Bay. Union Pacific's consultants are wrong when they interpret the absence of tidal fluctuations in A-Zone wells as evidence of a flow barrier.
- Data gaps exist where there are no monitoring wells downgradient of areas of soil contamination. One such gap is between the turntable and the southeastern wetland and southeastern ditch. Another such gap is in the northeastern part of the site where A-Zone ground water discharges into Humboldt Bay.

January 28, 2008

Benjamin Ross

A. Curriculum vitae, Benjamin Ross, Ph.D.

Work Experience:

1984 –	President of Disposal Safety Incorporated, a firm specializing in analysis of contamination by hazardous chemical and radioactive wastes. Developed computer model of underground gas flow at proposed Yucca Mountain nuclear waste repository. Published important scientific papers on multiphase flow in the subsurface, including the movement of dense non-aqueous phase liquids (DNAPLs). Reviewed numerous ground-water contamination investigations throughout the United States. Expert witness for the U. S. Dept. of Justice and private attorneys in numerous court cases, including *ICO v. Honeywell*, where he was the hydrogeology expert for plaintiffs who won an order requiring a $400,000,000 remediation. Edited issue of *Engineering Geology*: "Models of Nuclear Waste Repository Performance."
1992 – 1999	President of European Analytical Services, Inc. Represented a leading Russian scientific organization, the V. G. Khlopin Radium Institute, in U. S. sales of laboratory services and high-technology products.
1981 – 1984	Senior Research Scientist at GeoTrans, Inc.
1976 – 1981	Studied nuclear waste disposal at The Analytic Sciences Corp.
1975 – 1976	Energy Resources Company. Deputy Manager, Policy Division.

Education: A.B., Physics, Harvard University (summa cum laude), 1971.

Ph.D., Physics, Massachusetts Institute of Technology, 1976.

Committees: National Academy of Sciences, Board on Radioactive Waste Management, Committee on Remediation of Buried and Tank Wastes, 1993-2000.

USEPA Science Advisory Board, Subcommittee on Natural Attenuation Research, 2000.

USEPA Science Advisory Board, HLW/Carbon-14 subcommittee, 1992.

Languages: Fluent in French, good German and Russian, some Hebrew.

Scientific publications:

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B. Survey results

Streamborn Level Survey

Date/Time:	10-Jan-08
Project Name and Number:	Balloon Tract / P311
Project Location:	Waterfront Drive, Eureka CA
Instrument Operator:	Juli A. Brady
Rod Holder:	Ben Ross (Disposal Safety)
Weather:	Partly Cloudy / 60s
Datum:	NGVD29 (Mean Sea Level)
Instrument:	Nikon AP-7 Autolevel (30x)

Point	Known Elevation (ft)	Rod Measured Backsight (ft)	Height Instrument (ft)	Rod Measured Foresight (ft)	Calculated Elevation (ft)
MW-5A TOC NS	9.57	4.30	13.87		
MW4A TOC NS				4.97	8.90
MW-6AR TOC NS				3.80	10.07
MW-5A TOC NS				4.30 (check)	
Elev of MW-4A cited in reports by MFG	8.90				
Elev of MW-6AR cited in reports by MFG	10.07				

Streamborn Level Survey

Date/Time: 10-Jan-08

Project Name and Number: Balloon Tract / P311

Project Location: Waterfront Drive, Eureka CA

Instrument Operator: Juli A. Brady

Rod Holder: Pete Nichols (Humboldt Baykeeper)

Weather: Mostly sunny / 70s

Datum: NGVD29 (Mean Sea Level)

Instrument: Nikon AP-7 Autolevel (30x)

Point	Known Elevation (ft)	Rod Measured Backsight (ft)	Height Instrument (ft)	Rod Measured Foresight (ft)	Calculated Elevation (ft)
MW-5A TOC NS	9.57	2.25	11.82		
MW-4A TOC NS				2.92	8.90
1D				11.23	0.59
MW-5A TOC NS				2.25 (check)	
Elev of MW-4A cited in reports by MFG	8.90				
Measuring Point (MP) Description for 1D = Near TMS-2, there is a culvert on the eastern side of the reinforced-concrete wall. This culvert trends northeasterly (buried). The measuring point for 1D was on the ground surface, at the end of this culvert, immediately beneath the invert of the culvert.					

Streamborn Level Survey

Date/Time: 10-Jan-08

Project Name and Number: Balloon Tract / P311

Project Location: Waterfront Drive, Eureka CA

Instrument Operator: Juli A. Brady

Rod Holder: Pete Nichols (Humboldt Baykeeper)

Weather: Mostly sunny / 70s

Datum: NGVD29 (Mean Sea Level)

Instrument: Nikon AP-7 Autolevel (30x)

Point	Known Elevation (ft)	Rod Measured Backsight (ft)	Height Instrument (ft)	Rod Measured Foresight (ft)	Calculated Elevation (ft)
MW-6AR TOC NS	10.07	1.97	12.04		
MW-11A TOC NS				0.79	11.25
1Ba				9.80	2.24
1Bb				9.45	2.59
MW-11A TOC NS				0.79 (check)	
Elev of MW-11A cited in reports by MFG	11.25				
Measuring Point (MP) Description for 1Ba and 1Bb = There was a flooded wetland area in the southeast portion of the site. The measuring points 1Ba and 1Bb were ground surface shots - estimated (visually) to be the lowest elevations of the ground surface in this flooded wetland. Locations 1Ba and 1Bb were separated approximately 5 feet (horizontally). Lat./Long.: 40° 47' 57.53" N, 124° 10' 34.80" W. UTM: X=400768, Y=4517145.					

Streamborn Level Survey

Date/Time: 10-Jan-08

Project Name and Number: Balloon Tract / P311

Project Location: Waterfront Drive, Eureka CA

Instrument Operator: Juli A. Brady

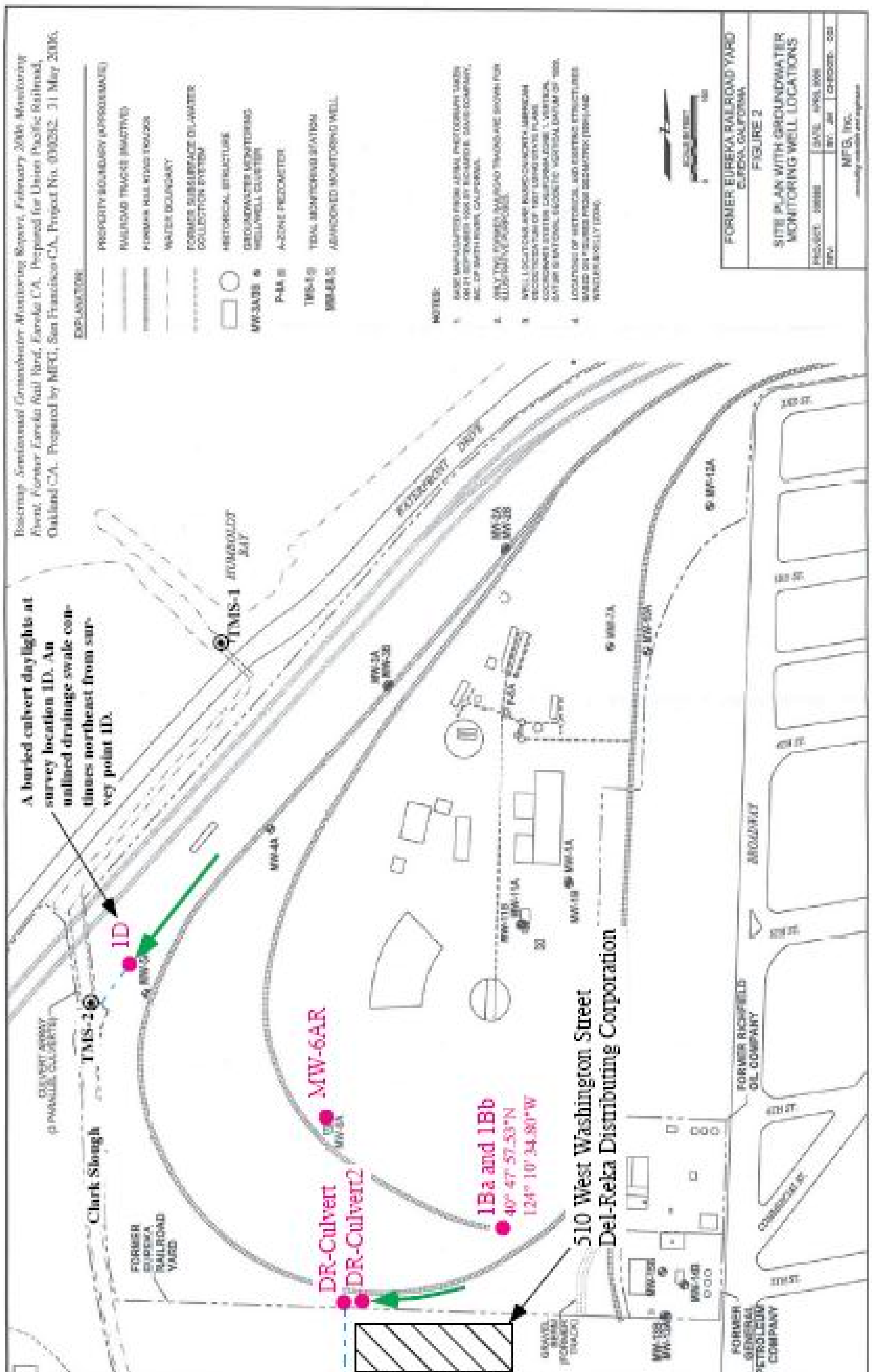
Rod Holder: Ben Ross (Disposal Safety)

Weather: Partly Cloudy / 60s

Datum: NGVD29 (Mean Sea Level)

Instrument: Nikon AP-7 Autolevel (30x)

Point	Known Elevation (ft)	Rod Measured Backsight (ft)	Height Instrument (ft)	Rod Measured Foresight (ft)	Calculated Elevation (ft)
MW-6AR TOC NS	10.07	2.33	12.40		
MW-5A TOC NS				2.83	9.57
DR-Culvert				9.75	2.65
DR-Culvert2				9.25	3.15
MW-6AR TOC NS				2.33 (check)	
Elev of MW-5A cited in reports by MFG	9.57				
Measuring Point (MP) Description for DR-Culvert = Ground surface, directly beneath the end of the culvert, at the centerline of the culvert. The culvert extends beneath 510 West Washington Street.					
Measuring Point (MP) Description for DR-Culvert2 = Ground surface, approximately 8 feet upstream from DR-Culvert, at the center of the drainage swale.					
DR = Del-Reka Distributing Corporation, located at 510 West Washington Street. A culvert (DR-Culvert) drains an unlined drainage swale along the southern property boundary of the Balloon Tract. The culvert extends beneath the 510 West Washington Street.					



Note: Locations are approximate.

- Streamborn Survey Points 10 January 2008
- Streamborn Tidal Monitoring Survey Points 30 July 2007
- Buried Culvert
- Unlined Drainage Swale (with flow direction)

C. Influence of tides on ground water

More than half a century ago, the noted hydrogeologist J. G. Ferris[4] derived a formula for tidal fluctuations in wells. He found an analytical solution to the equations for the head in a confined aquifer in contact with a surface water body with cyclically varying water levels, such as a tidal estuary. Ferris's formula is reprinted in the book by Walton. [34] Ferris found that in a uniform, perfectly confined aquifer, the amplitude of tidal fluctuations declines exponentially with distance from the shore. His solution can be written as

$$s^*(t) \quad = \quad s_h \; e^{-x/\lambda} \; \sin\left(\omega t - \frac{x}{\lambda}\right) \tag{1}$$

$$\omega \quad = \quad 2\pi/t_s \tag{2}$$

$$\lambda^2 \quad = \quad t_s T/\pi S \tag{3}$$

where s^* is the difference between instantaneous and mean head in an observation well; t is time; s_h is the amplitude (or half range) of stream-state change; x is the distance from the shoreline (or, if the top of the aquifer is below sea level and the estuary has a sloping bottom, the point offshore where the aquifer contacts the estuary); $t_s = 696$ minutes is the tidal period (the time between high tides); T is the transmissivity of the aquifer, and S is the storage coefficient of the aquifer. A quantity easily measured in the field is the tidal range s_r, the difference between the high and low water levels in a well. Walton's Eq. (5.211) [34] gives this formula:

$$s_r \quad = \quad 2 s_h \; e^{-x/\lambda} \tag{4}$$

Equation (3) shows that λ, the characteristic distance of the problem, is proportional to $T^{1/2}$ and to $S^{-1/2}$. Moving a distance λ away from the shore reduces the tidal range by a factor of e.

While this solution is derived for a confined aquifer, it also provides an approximate description of tides in an unconfined aquifer. (It is an exact description in the limit where the tidal range is very small compared to the aquifer thickness.)

Storage coefficients are vastly greater in unconfined aquifers than in confined aquifers. Values of S for confined aquifers range from 0.005 to 0.00005, while in unconfined aquifers they are usually between 0.01 and 0.30. [8] Thus S is typically at least two orders of magnitude greater in unconfined than in confined aquifers. At the Balloon Track site, T is probably substantially greater in the confined B Zone than in the unconfined A Zone, because both have similar lithologies (predominantly poorly sorted sands) and the saturated thickness of the B Zone is an order of magnitude greater. Thus λ is at least an order of magnitude greater in the B Zone than in the A Zone.

Geomatrix [12] measured tidal fluctuations in three well pairs screened in the A and B Zones. They observed fluctuations in the B-Zone wells, but not in the A-Zone wells and inferred from this observation that

[4] J. G. Ferris, Cyclic fluctuations of water levels as a basis for determining aquifer transmissibility, *Int. Assoc. Sci. Hydrol. Gen. Assem. Brussels, Pub. 33*, vol. 2, 1951, cited in [34].

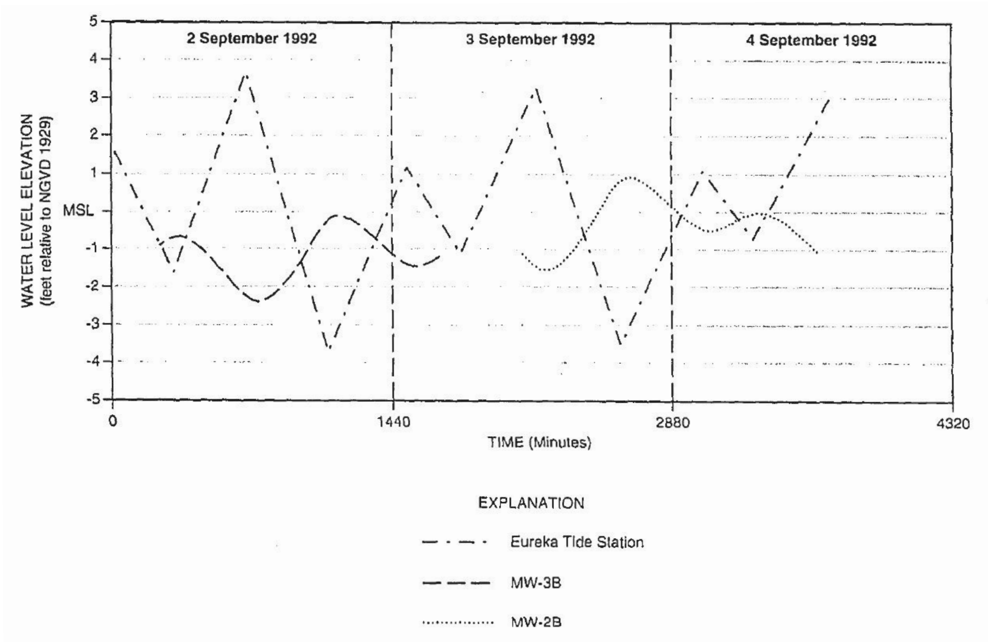


Figure 9: Geomatrix tidal data.

> These data suggest that a barrier to groundwater flow is present in the A Zone west of MW-2A and MW-3A and that the A Zone is not hydraulically connected to the bay in this area.

This inference has been cited as fact in subsequent documents by Geomatrix and other Union Pacific contractors. [14, 15, 20, 21]

The inference is incorrect. This can be shown by a simplified analysis of the Geomatrix tidal data, setting the tidal range equal to the difference between the high high tide and the low low tide. The data are shown in Fig. 9. The measured tidal range was 2.3 ft in both MW-2B and MW-3B, while the tidal range in the bay was approximately 7 ft. [12] This represents an attenuation factor of $e^{-x/\lambda} = 0.33$ or $x/\lambda = 1.11$. Because the A-Zone is unsatured, x/λ at the co-located A-Zone wells is at least 10 times greater. If the A and B Zones are both well connected to Humboldt Bay, the range of tidal fluctuations in MW-2A and MW-3A would be expected to be less than $7 \times e^{-11} = 10^{-4}$ ft or no more than about a thousandth of an inch. With no measurable tidal fluctuations expected in those two wells even if they are directly connected to the bay, the lack of such fluctuations provides no evidence whatsoever for the absence of a hydraulic connection.

A more detailed analysis gives additional insight into the tidal fluctuations in the B Zone. The tide in Humboldt Bay is the sum of a 12-hour cycle and a 24-hour cycle. The range of the 24-hour cycle in the bay is the difference of the midpoints of the two rising legs of the tide, or about 2.2 ft. The range of the 12-hour cycle is the difference between the mean of the two high tides and the mean of the two low tides, about 5 ft. Because Eq. (3) shows that λ is proportional to $t_s^{1/2}$, the attenuation distance will be greater by a factor of 1.41 for the 24-hour cycle than for the 12-hour cycle. At a distance of $2\lambda_{24}$ from the shore, the range of the 24-hour fluctuations will be $2.2e^{-2} = 0.30$ ft and the range of the 12-hour fluctuations will be $5e^{-2.82} = 0.30$ ft. Farther inland, the 24-hour fluctuations will have greater amplitude than the 12-hour fluctuations. (This magnification of 24-hour oscillations compared to the 12-hour oscillations is visible in the tidal record of Well MW-2B on the figure.) Fluctuations with longer periods (such as water-level increases driven by storm winds) would penetrate even farther inland.

Thus water levels in B-Zone wells that are too far inland to detect 12-hour tidal fluctuations may nevertheless be affected by water-level fluctuations in the bay. Although the effects would be small—a fraction of a foot—they might still be significant compared to the small gradients seen in the B Zone. This source of uncertainty should be considered when interpreting flow directions in the B Zone.

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[4] T. L. Eckard and S. E. Goodin, Geomatrix, letter to J. Fleck, RWQCB, July 16, 1992, UP09507-09509.

[5] T. L. Eckard and S. E. Goodin, Geomatrix, letter to C. Wright-Shacklette, RWQCB, Aug. 19, 1992, UP09503-09506.

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